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Fabrication of Improvised Dye-Sensitized Solar Cells from Mangosteen Pericarp Extract

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ABSTRACT

Recent researches are geared towards finding alternative sources of renewable energy and solar power seems to be an attractive avenue and currently, dye-sensitized solar cells (DSSC) have gained worldwide attention. This study aimed to fabricate DSSC that makes use of an improvised conductive glass, with zinc oxide in nappy cream as photoanode and mangosteen pericarp extract as a sensitizer. It sought to find the effect of DSSC processing on the conductivity and performance in terms of current, voltage, and power density generated, and evaluate its stability. Ordinary 1/8” mirror was made conductive glass by stripping the gray coat with very fine sandpaper then heating to remove the orange coat. Conductivity was good (2.1 ohms) and etching with povidone-iodine provided transparency for the photoanode. The DSSCs were capable of producing a mean current of 0.0007 mA and mean voltage of 2.8670 mV that last for ninety minutes. The present study showed DSSCs could be constructed using indigenous materials. Further research is needed for finding ways to improve its efficiency and lifespan. By knowing the principles of the DSSCs, and enhancing the innovativeness and creativity of the current DSSC, researchers can overcome the lack of expensive materials and equipment for future studies.

Keywords — dye-sensitized solar cells, energy, experimental, DSSCs, conductive glass, processing time, a halogen lamp, monophasic, Philippines

INTRODUCTION

Current researches are geared towards finding alternative sources of renewable energy. Recently, dye-sensitized solar cells (DSSC) have gained worldwide attention. Basically, DSSCs require conductive, transparent and sturdy glasses which are either coated with indium- or fluorine-doped tin oxide to allow the measurement of their light-harvesting capacities. But these are expensive and are not readily available (Grätzel, 2003). Titanium dioxide (TiO2) and zinc oxide (ZnO) are popular as a wide band gap nanocrystalline semiconductor oxide electrode (as an electron acceptor) in the DSSC.

The use of natural dye extracts provides natural, non-toxic and low-cost sources with high absorbance level of ultraviolet, visible and near infrared (Ramachary and Shashank, 2013). Natural dyes have become a viable alternative to expensive organic sensitizers because of their low cost of production, abundance in supply, and eco-friendliness (Yusoff, Kumara, Lim, Ekanayake, & Tennakoon, 2014). Photosensitizers are natural dyes bound to TiO2. Upon absorption of a photon, the dye molecule gets oxidized and the excited electron is injected into the TiO2 nanostructure. Natural dyes that have been shown to have promising light harvesting efficiency are extracts of henna, cherries, pomegranate and raspberries, to name a few. There are hundreds and possibly thousands of natural dyes that are potential candidates as sensitizers in the manufacture of DSSC. According to the study conducted by Prabavathy et al. (2017), the efficiency of natural dyes is not up to the mark mainly due to anthocyanin instability. Moreover, the stability issues in vitro are mainly due to the effect of solvents on the extraction of anthocyanins and their respective pH. In addition, the performance of DSSCs are often measured using short-circuit current (I_{sc}) in mill amperes and open-circuit voltage (V_{oc}) in millivolts.

There were no local data available on the construction of a dye-sensitized solar cell, much more the use of improvised materials. Thus this study provides baseline information on improvising DSSCs from locally available materials.

This study made use of an improvised conductive glass from cheap ordinary 1/8” mirrors. Insights are gained on how to prepare them and how processing may have an impact on the preservation of conductive property while maintaining the required transparency to light. This study also made of zinc oxide, which showed relative ease of preparation as photoanode. Many factors could contribute to the functioning of an improvised DSSC as well as its light-harvesting capacity or performance. In search of possible alternatives to the standard components of the DSSC, the author hopes to give inspiration to other young researchers on the importance of innovativeness and creativity in problem solving.

DSSCs’ relative instability may be due to evaporation of electrolyte solution and the photodiegradation of the dye itself. This study provided baseline data on improvised DSSC’s stability, which may help in the search for possible ways to enhance or even prolong their stability. All this information is needed for the future development and applications such as wearable technology.

This study aims to fabricate dye-sensitized solar cells that makes use of an improvised conductive glass, with zinc oxide in nappy cream as photoanode and mangosteen pericarp extract as sensitizers. These materials are available locally. Specifically to determine the effect of DSSC processing steps on the conductivity of an improvised conductive glass; to evaluate the performance of improvised DSSC containing extracts of mangosteen pericarp as photoanode sensitizer in terms of the following: (a) current in milliamperes, (b) voltage in millivolts, and (c) power density in watt per square meter; and to evaluate the stability of improvised DSSC containing extracts of mangosteen pericarp extract as sensitizers under ambient light and a 100-watt halogen lamp.

METHODOLOGY

Research Design

The experiment was divided into four parts: (1) preparation of materials; (2) dye-sensitization of photoanode; (3) assembly of the DSSC; and (4) testing the performance of the assembled DSSC. The materials prepared were the conductive glasses, mangosteen peel dye, the zinc oxide photoanode, the electrolyte, and the counter-electrodes. The scheme of methods is presented in Figure 1.

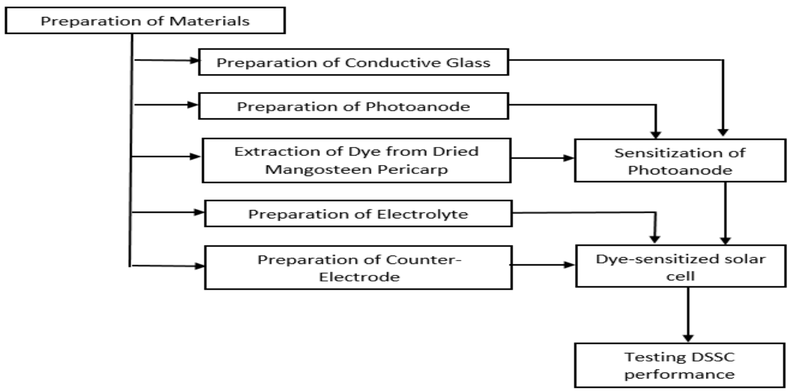

Figure 1. Scheme for the preparation of materials, assembly, and performance testing of DSSC.

Preparation of the Materials

Preparation of Conductive Glass. Thirty 4cm x 6cm ordinary reflective mirrors were prepared for etching. The etching process was done in the following manner: The glass was wetted with soapy water. With the painted side towards the etcher, the glass was held at a 45 ^{0} angle on a piece of cloth. It was etched with #1000 sandpaper until the red bricklayer was uniformly exposed. The glass slides were placed paint-side-down on a wire gauze over a burner and heated at 150^{0}C for 7 minutes then allowed to cool for 2 minutes before being transferred to a dry rack. After cooling, the orange coat of glass slides was rubbed off with cotton balls to expose the underlying metallic coat. Conductivity was tested using a multimeter. Pair of conductive glass slides were designated either as a photoanode or a counter-electrode. For the photoanode, tapes were applied to four edges of the slide leaving a 2cmx2cm window in the middle area, which was etched with a betadinized cotton ball. After a semi-transparent window was made, the tapes were removed and the photo-anodes were stored individually in paper envelopes. The counter-electrodes did not have windows and were also stored individually in paper envelopes. Suitability criteria include uniform conductivity of less than 10 ohms and transparency for shined light.

Extraction of Dye from Dried Mangosteen Pericarp. Mangosteen pericarps were air-dried for three days. 100 grams of samples were cut into small pieces and placed in a beaker. 200 mL of 70% ethanol was then added. The mixture was allowed to sit for 24 hours then vacuum-filtered. The 100mL extract was reduced to 80mL in an 80^0C-hot water bath for an hour. The dye was allowed to cool before storing in a dark bottle.

Preparation of Photoanode. Zinc oxide paste was prepared using 45 grams of commercial nappy cream. Two to three drops each of white vinegar and liquid detergent were then added. The mixture was put to a boil over a burner for 5 minutes and stirred until there was a separation of a liquid and a brownish residue. The liquid part of the mixture was decanted. The residue was cooled and then stored in a small bottle.

To prepare the photoanode, the conductive side of the glass slide was cleaned using acetone in cotton balls. The glass slide was taped to a flat surface using scotch tape. The tapes covered 5mm of the glass slide on three sides and 2cm on the remaining side. Five drops of zinc oxide paste were placed on the untapped portion of the photoanode spread to form a uniformly thin layer using one edge of a PVC card. The zinc oxide layer was then air-dried for two hours. The zinc oxide slides were calcinated for one hour at 150^0C on an aluminum foil on a wire gauze over a stove. The slides were then allowed to cool before storage.

Preparation of Electrolyte. Four mL of radiator coolant (anti-freeze) were mixed with one mL 10% povidone-iodine solution. The mixture was labeled and set aside.

Preparation of Counter-Electrode. The conductive side of the glass slide was adhered to an 8cm x 25cm piece of cardboard using masking tape. The tapes covered 5mm of the glass slide on three edges and 2cm on the remaining edge. The untaped middle part measured 3cm x 3cm similar to the photoanode. The glass was passed lightly over and slightly touching the flame of a candle until a uniform layer of soot was formed. It was allowed to cool.

Sensitization of Photoanode

The zinc oxide-coated photoanodes were laid on a flat bottomed container. Several drops of the dye were placed to cover the entire surface of the zinc oxide layer completely. The dyes were allowed to sit for 24 hours. After sensitization period, the photoanodes were rinsed with distilled water then air-dried.

Assembly of the DSSC

The 3cm x 3cm middle areas of the photoanode and the counter-electrodes were joined facing each other with the longer conductive ends oriented away from each other. Binder clips were applied to either side of the joined slides to form the DSSC. Two to three drops of electrolyte were then placed in one of the edges of the contacted sides then allowed to diffuse inward into the center of the assembly. Conductivity was tested using a multimeter. The DSSC was sealed using superglue applied to the edges where photoanode and the counter-electrodes made contact. The DSSC was attached to the multimeter. The black electrode of the multimeter was clamped to photoanode while the red electrode was attached to the counter-electrode.

Testing the performance of the DSSC

Under ambient light, the current and voltage of the DSSC were measured. Then the 100-watt halogen lamp was switched on and the current and voltage of the DSSC were measured. Data were recorded. The measurements were taken and recorded every half-hour until such time the DSSC no longer gave output readings.

RESULTS AND DISCUSSION

This study was conceptualized to actually construct an improvised dye-sensitized solar cell *(*DSSC) using locally available materials to produce alternative sources of renewable energy "green energy" while harnessing solar power.

Improvised conductive glass. The preparation of a conductive glass that serves as the substrate for the DSSC was a major challenge. First, using the conventional reflective mirror was done because of its conductive metallic layer. But the challenge was how to keep the conductive material intact. Therefore, the utilization of various materials and techniques (Table 1) before arriving at the "best method" to obtain a uniformly conductive glass while maintaining transparency was implemented.

Table 1. Various Materials and Techniques Used For the Preparation of Suitable Improvised Conductive Glass

Material	Technique	Observation/comments
Clear 1/8" glass	Etching pencil lead to deposit graphite layer on the glass	• Produced a flimsy conductive layer which easily rubs off after heating and exposure to iodine
Ordinary 1/8" mirror	Stripping the reflective coat of the glass mirror using #1000 sandpaper	• Leaves only a small amount of metallic layer on the glass, although initially conductive, it deteriorates upon subsequent calcination, dye-sensitization, and exposure to iodine electrolyte
Ordinary 1/8" mirror	Stripping the gray paint coat of the glass mirror using #1000 sandpaper then heating to 150^{0}C for 7 minutes to remove the orange coat	• Good conductivity with the resistance of 2.1 ohms, but very limited transparency • Possible to create a semitransparent window by taping off a middle square area 2cmx2cm to be etched with 10% povidone-iodine • Avoid exposure to povidone-iodine

Results of the experiment revealed that the "best" method for preparing an improvised conductive glass involved stripping the gray paint coat of the glass mirror using #1000 sandpaper then heating to remove the orange coat. This method resulted in good conductivity. The problem of limited transparency to light was addressed by creating a transparent window using povidone-iodine.

Grätzel (2003) and Hagfeldt, Boschloo, Sun, Kloo, & Pettersson (2010) mentioned that it is significant to preserve the conductive property of the conductive glass throughout the entire experiment as the glass is exposed to heat as well as chemical treatment with povidone-iodine. However, results showed that because the conductive glass was improvised, the performance is not similar to the commercial indium-tin-oxide (ITO) or fluorine-doped tin oxide (FTO) glasses that are sturdy and have reliable transparency and conductivity. This was shown in the relative loss of conductivity observed upon sealing the DSSC with methylmethacrylate (Table 2). Nevertheless, the DSSC was observed to be capable of producing current and voltage, although small and short-lived.

Processing Step. This study also aimed to determine how various processing steps affects the conductivity of improvised conductive glass. This is to ensure that the conductive property of the improvised conductive glass is preserved throughout the entire experiment as the glass was exposed to heat as well as chemical treatment with povidone-iodine. Results were presented in Table 2.

Table 2. Effect of Processing Steps on the Conductivity of Improvised Conductive Glass (units in ohms)

PROCESSING STEP	SAMPLE					RANGE	MEAN±SD
	1	**2**	**3**	**4**	**5**		
Photoanode: before calcination	2.1	2.1	2.5	2.2	2.3	2.1-2.5	2.24±0.17
Photoanode: after calcination	2.5	2.7	2.7	2.5	2.6	2.5-2.7	2.60±0.10
Photoanode: after dye-sensitization	2.9	2.8	3.0	2.7	2.8	2.7-3.0	2.84±0.11
Counter-electrode: after carbon soot deposition	2.2	2.1	2.5	2.3	2.3	2.1-2.5	2.28±0.15
DSSC: Introducing the electrolyte	38.0	23.0	45.0	22.0	31	22.0-38.0	31.8±9.8
DSSC: Sealing with methyl methacrylate	266	254	223	251	248	223-226.0	248.4±15.76

Based on the presented results (Table 2), the improvised conductive glasses were highly conductive. The conductivity did not significantly change during the preparation of the photo-anode despite heating and dye-sensitization.

There was a ten-fold increase in the resistance, hence decreased conductivity, with the introduction of the iodine-containing electrolyte. This may be due to the corrosive effect of iodine on the metallic layer of the conductive glass. Moreover, the relative loss of conductivity, shown in the hundred-fold increase in resistance, was observed upon sealing the DSSC with methyl methacrylate. Despite the relative loss of conductivity after sealing, the DSSC was noted to generated current and voltage as produced by the improvised DSSC under ambient light (Table 3) and under a 100W halogen lamp (Table 4).

Performance of Improvised DSSCC under ambient light. The average performance of three improvised DSSCs under ambient light was also determined. The current and voltage outputs were measured every half-hour from the time the electrolyte was introduced and the electrodes were sealed. Results are shown in Table 3.

Table 3. Average Current, Voltage and Power Densities of Three Dsscs under Ambient Light

Time from Adding Electrolyte and Sealing	CURRENT (mA) Mean ± SD	VOLTAGE (mV) Mean ± SD	POWER DENSITY (W/m^2) Mean ± SD
0	0.0000 ± 0.00	0.8000 ± 0.10	0.0000 ± 0.00
30	0.0003 ± 0.00	0.1400 ± 0.00	0.0023 ± 0.00
60	0.0010 ± 0.00	0.0700 ± 0.06	0.0033 ± 0.00
90	0.0007 ± 0.00	0.0000 ± 0.00	0.0000 ± 0.00
120	0.0000 ± 0.00	0.0000 ± 0.00	0.0000 ± 0.00

Findings revealed that under ambient light, a small amount of current was generated 30 to 60 minutes after adding electrolyte and sealing. There was a generation of voltage immediately after adding electrolyte and sealing, which is persistent even after 60 minutes. Power density, although very small, was appreciated only 30 to 60 minutes after adding the electrolyte and sealing. These results further suggest that it is possible to make an improvised DSSC.

Performance of Improvised DSSCC under 100W Halogen Lamp. To determine the performance of three improvised DSSCs under a 100W halogen lamp, the current, voltage and outputs were measured every half-hour from the time the electrolyte was introduced and the electrodes were sealed.

Table 4. Average Current, Voltage and Power Densities of Three DSSCS under A 100W Halogen Lamp

Time From Adding Electrolyte and Sealing	Current (MA) Mean ± SD	Voltage (MV) Mean ± SD	Power Density (W/M^2) Mean ± SD
0	0.0020 ± 0.00	2.4700 ± 0.65	0.2500 ± 0.07
30	0.0010 ± 0.00	27.670 ± 3.00	1.3800 ± 0.15
60	0.1000 ± 0.00	21.470 ± 1.00	1.0700 ± 0.05
90	0.0007 ± 0.00	2.8670 ± 4.40	0.1400 ± 0.22
120	0.0000 ± 0.00	0.0007 ± 0.00	0.0000 ± 0.00

As shown in Table 4, results found out that under a 100-watt halogen lamp, a small amount of current was generated immediately after adding electrolyte and sealing and was persisted 90 minutes thereafter. Likewise, the voltage was generated after adding electrolyte and sealing persisted even after 90 minutes. Power densities under a 100-watt illumination were bigger than those under ambient light. Although small, power density was appreciated even at 90 minutes after adding the electrolyte and sealing.

Results suggest that there seems to be a monophasic trend, which is characterized by a peak at 30 minutes after adding electrolyte and sealing, followed by decay, or wane, in terms of generation of current and voltage, hence, in power density. Return to baseline levels was noted 90 minutes after adding electrolyte and sealing. No current or voltage was appreciated 120 minutes after adding electrolyte and sealing. The half-life of the assembled DSSCs was shorter than two hours. Therefore, results show that it is possible to improvise functional DSSCs using indigenous materials.

Several researchers and experts long recognized that the limited half-life and efficiency of DSSCs are among the challenges in research and development (Hagfeldt & Grätzel, 2000; Grätzel, 2001; Grätzel, 2003; Baxter, 2010; Hagfeldt, Boschloo, Sun, Kloo, & Pettersson 2010; Afifi & Tabatabaei, 2014). The low efficiency (<12%) were due to the use of low red and near-IR absorption of the dyes and the requirement for a high surface area. The concern on stability is mainly due to the electrolyte (being liquid and corrosive) and requires 10^8 turnovers of dye required for a 20-year lifetime for commercial DSSCs (Baxter, 2010).

Nevertheless, the findings revealed that the need for expensive conductive glasses can be addressed using a cheap alternative if the objective is to demonstrate photovoltaics in the college/university setting. The DSSCs can be constructed using indigenous materials. After establishing a baseline, further research is needed for finding ways to improve the efficiency and half-life of improvised DSSCs. Furthermore, results show that knowing the inner workings of the DSSCs can offset the lack of expensive materials and equipment.

The results of the present study was in conformity with the findings reported by Grätzel (2003) and Hagfeldt, Boschloo, Sun, Kloo, & Pettersson (2010) that "dye-sensitized solar cells are attractive because they are made from cheap materials that do not need to be highly purified and requires simple construction (Grätzel, 2003; Hagfeldt, Boschloo, Sun, Kloo, & Pettersson, 2010).

CONCLUSIONS

While the preservation of the conductive property of the conductive glass is desired, results showed that because the conductive glass was improvised, there was a relative loss of conductivity observed upon sealing the DSSC. Nevertheless, the DSSC was observed to be capable of producing current and voltage, although small and short-lived.

The improvised DSSCs followed a monophasic trend, with a peak at 30 minutes, followed by a decline, then a return to baseline levels 90 minutes after adding electrolyte and sealing. Power densities under a 100-watt illumination were bigger than those under ambient light. The low power densities showed the very limited efficiency of the DSSCs. In addition, the half-lives being shorter than two hours showed the instability of the improvised DSSCs.

TRANSLATIONAL RESEARCH

The findings of the study showed that the need for expensive conductive glasses can be addressed by using a cheap alternative power source if the aim is to demonstrate photovoltaic in the college/university setting. Moreover, DSSCs can be constructed using indigenous materials and knowing the inner workings of the DSSCs, lack of expensive materials and equipment can be counterbalanced. After establishing baseline information, further researches are needed for finding ways to improve the efficiency and half-life of improvised DSSCs.

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